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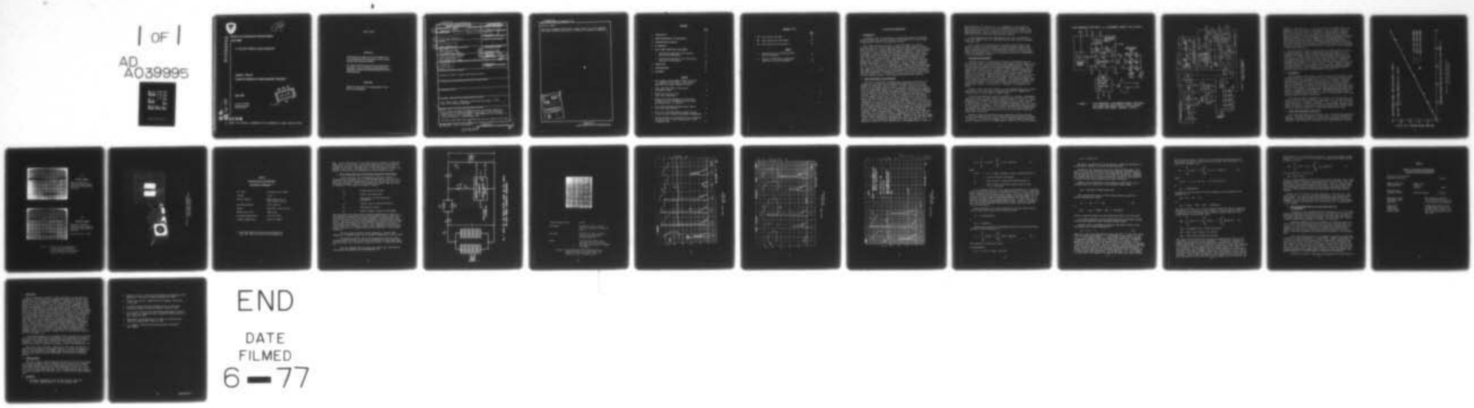

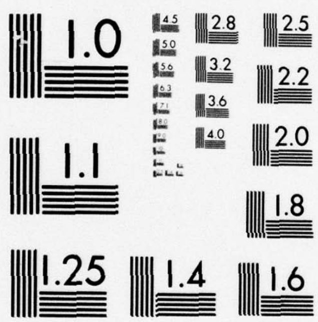

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Research and Development Technical Report

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A SOLAR POWER RADIACMETER

Joseph C. Nirschl

Combat Surveillance & Target Acquisition Laboratory

April 1977

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A solar power radiacmeter (breadboard) design is described, based on a miniature (18 cc) ionization chamber and low power, solid-state (Field Effect Transistor, FET) electrometer. Power demand for this instrument, including DC converter, is approximately 5 mW.

Preliminary experiments with a 20 cm^2 Silicon solar cell panel and pen light → OVER

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(AA size) rechargeable (NiCd) battery suggest feasibility of this approach. Solar power intake and dissipation is discussed for experiments conducted.

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A Solar Power Radiacmeter

1. INTRODUCTION

The growing trend for conservation of energy and search for alternate sources of energy has spurred interest in solar power for a diverse range of applications, both of a large and small scale.

This report describes the use of a relatively small size (20 cm^2 collector area) Silicon solar panel to power a portable radiation survey meter (radiacmeter). Such a combination invites consideration, particularly for military or Civil Defense type radiacmeters, because in remote locations or emergency situations fresh batteries may not always be on hand; while solar power, although dependent on geographic location (latitude), diurnal cycle and weather, can be expected to be available at least part of the time. Also, in conjunction with a rechargeable (Nickel-Cadmium, NiCd) battery the fluctuations in solar power availability and level can be compensated and bridged, to a tolerable degree. Such a scheme was suggested earlier (references 1 and 2) as advances in low-power, linear integrated circuit (I.C.) and solar cell technology made it appear feasible and economical. Solar cell panels of the size required for the radiac application are now commercially available at a cost of approximately $15.00 (reference 3) which may be expected to decrease substantially in the future (reference 4). The work reported here is preliminary in nature and was performed as a low-priority sideline project, to the extent permitted by other workload.

2. POWER REQUIREMENTS FOR RADIACMETER

The type of radiacmeter considered here is naturally one that by its prospective field usage does not demand appreciable power, but is still capable of performing a useful function. A simple, low cost instrument, such as the IM-174B/PD presently used by the Army, has operational characteristics (measurement range from 1 to 500 Rad/h) attainable, and compatible with, a compact, solar-powered radiacmeter design. The IM-174B, for example, requires typically 30 mA supply current from one BA-30 type battery (1.5 V) or 45 mW. A major portion of this power is needed for the electrometer tube's (CK5886) filament supply, which can be eliminated by application of present day Field Effect Transistor (FET) technology. Be replacing the vacuum tube with a micropower solid-state electrometer, while retaining the ionchamber as a detector (although changed from unsaturated to an essentially saturated mode of operation), and retaining also a D'Arsonval meter for readout, the power demand for the radiacmeter was reduced to 5 mW (from battery). At the same time, the dynamic range of the instrument was extended and its accuracy (readability) increased. Although no real package design was attempted in this breadboard phase, it appears that with a small (180° taut-band) meter and penlight-size battery, instrument size and weight can be greatly reduced, compared to the IM-174B/PD. Because of the low power demand (5 mW) of this radiac design, employment of a small size (20 cm^2) solar panel seems to be quite feasible to provide sufficient primary power for its operation, particularly when combined with a rechargeable battery (such as a

NiCd cylindrical or button cell). It is noteworthy in the context of solar energy that the level of solar irradiance onto the surface of the earth (at some 10^8 miles from the sun) is of the order of 1 kW/m^2 or 100 mW/cm^2 (peak-power, based on such conditions as sea level, sun in zenith, clear sky and low precipitable water and dust content).

If one assumes prevailing conditions far from ideal, an estimate of 10% of the 1 KW/cm^2 figure of 10 mW/cm^2 might be a more realistic average irradiance level.

With a typical 10% efficiency and ca 20 cm^2 collection area of the solar cell panel, this should amount to a collected power level of some 20 mW. Peak power levels (in bright sunshine, through a window) of up to about 90 mW were measured with the panel used in this work, with average levels during daylight hours, over a two-week test period, of approximately 14 mW (see paragraph 5 below).

3. RADIACMETER/ELECTROMETER

The basic circuit is illustrated in Figure 1, which depicts the two main portions, namely the FET operational electrometer and the toggle circuit for control of the latching reed relay (high impedance switch). Details of this switching arrangement are described elsewhere (reference 5). The advantage of the relay is that it permits all high impedance connections to remain within the (RTV sealed) ionchamber module. Only on the 1000 Rad/h range is the relay activated (contact K shorts High Meg resistor R1) to reduce the electrometer feedback resistance (to retain linearity and prevent amplifier saturation). Range switch S1 permits selection of three (full scale) dose-rate ranges (10, 100, 1000 Rad/h). The ionization chamber used is a miniature design (18 cm^3 active volume), which affords reasonably good (within 10%) linearity over the dynamic range, at relatively low (12 V) polarization voltage. Its sensitivity is typically 1.6 picoamperes per Rad/h.

Figure 2 gives a detailed schematic of the breadboard solar power radiacmeter design. The input stage is comprised of a dual FET (AD830) and a constant current source (based on a Zener diode).

The following operational amplifier (uA776) is a low power, programmable type, which, with a 10 Mohm resistor connected between pin 8 and $-V_S$ (-12 V), operates on 25 microamperes quiescent supply current, or a power dissipation of approximately 0.6 mW. The total electrometer consumes only 2.5 mW, a fraction of which is used to drive a D'Arsonval (taut-band) meter full scale, in this case 25 microamperes. With the small ionchamber the voltage swing of the electrometer output is 0.9 V, 9 V and 9 V for the three selectable dose-rate ranges, with calibration resistors (in series with meter) providing proper meter indications.

Because of the excellent matching and temperature tracking characteristics of the AD830 Dual FET only an internal zero adjust control is presently provided. It was noticed, though, that at elevated (+50°C) temperatures the gate leakage current of the AD830 caused a (25% of full scale) zero offset

HIGH IMPEDANCE DETECTOR (e.g. IONCHAMBER) MODULE (RTV SEALED)

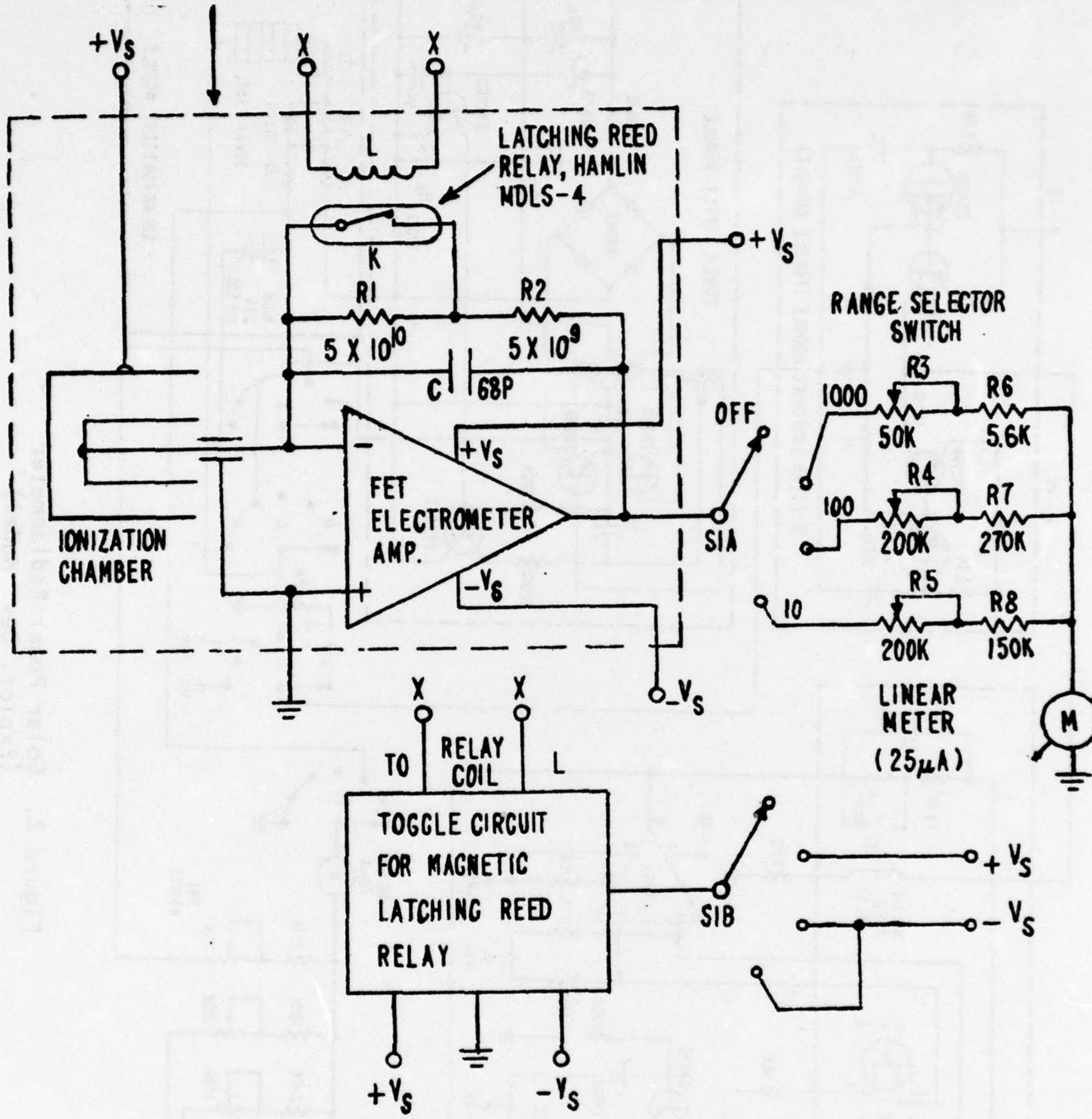


FIGURE 1 HIGH IMPEDANCE (ELECTROMETER RANGE) SWITCHING IN A RADIATION SURVEY METER, WITH LATCHING REED RELAY AND TOGGLE (CONTROL) CIRCUIT

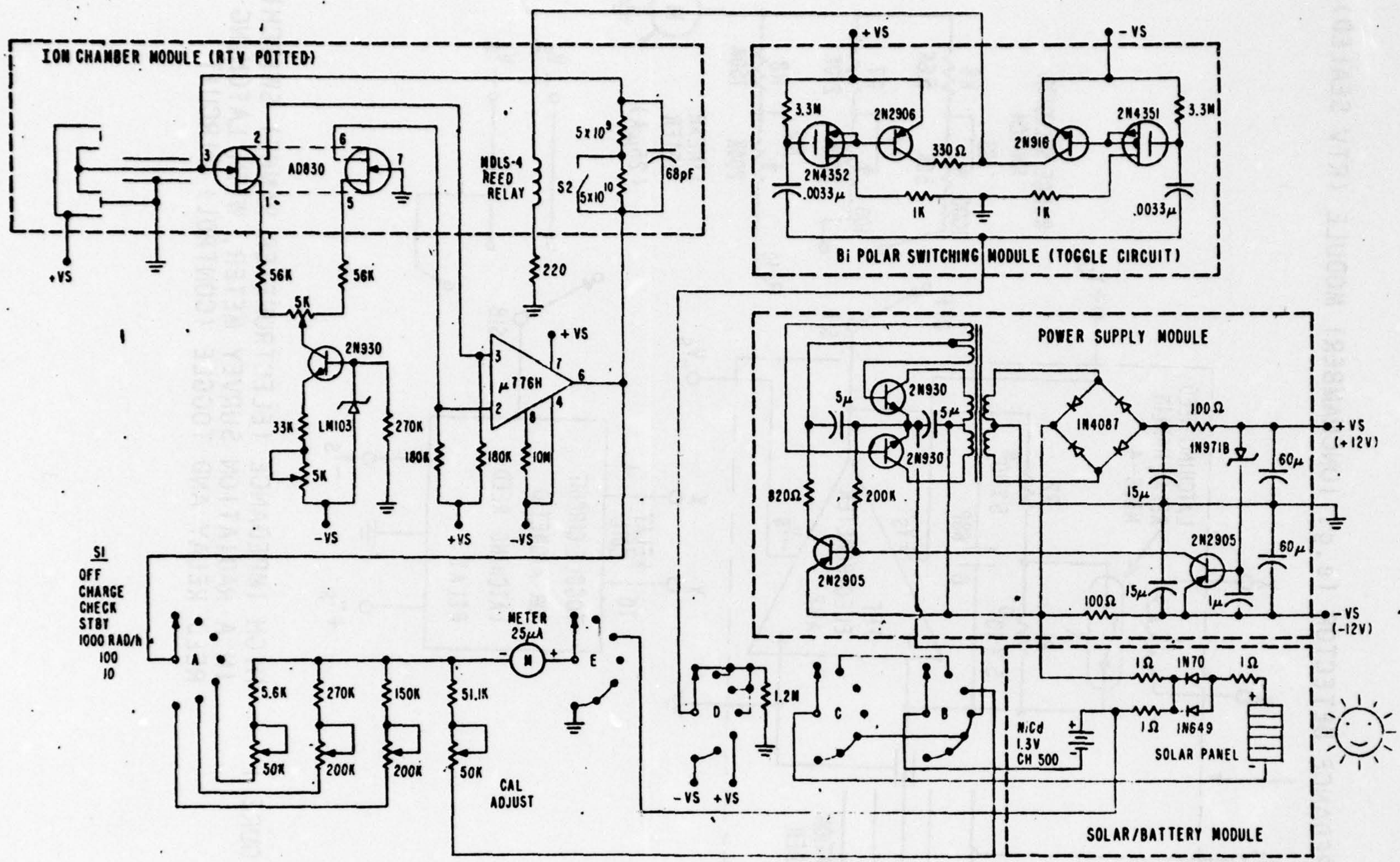


Figure 2. Solar Power Radiacmeter
(Explor. Dev. Model)

compared to room temperature, on the most sensitive (10 Rad/h) range (with negligible effect on the two higher ranges). Also, upon power turn-on, there is an occasional offset noticeable (on 10 Rad/h range), attributed to a transient charge, which then decays to a negligible level (within about two minutes). These conditions are considered correctable by transient suppression and by use of a dual MOSFET (e.g., type DMO 6A) device in the input stage of the electrometer, although at the disadvantage of more delicate handling of such a device (to prevent damage to metal oxide layer from static charges) during assembly. No effort was made so far to optimize the design of the solid-state electrometer, as the primary interest centered on solar power operation.

The relay control (toggle) circuit (Bipolar switching module in Figure 2) consumes power only during rangeswitching, when the relay coil L is latched or unlatched. Apart from the three measurement ranges, switch S provides for a "CHARGE" position, where the full solar panel current flows into the battery, and a "Check" position, where the meter is connected as a voltmeter, thus permitting readout of the battery voltage. Radiation measurement performance of the radiacmeter was checked by exposure to Cs-137 and Co-60 gamma radiation, as shown in Figure 3. Also, transient response to a step excitation of beta radiation (on 10 Rad/h and 100 Rad/h range) is recorded in Figure 4. The breadboard (exploratory development) model of the solar power radiacmeter is photographed in Figure 5.

4. DC CONVERTER

The DC converter (power supply, Figure 2) provides the necessary voltage step-up and dual polarity regulated (±12 V nominal) supply voltages to permit operation of the radiacmeter off a single (1.3 V) battery. Although this could be a BA-30 (D size, Leclanche type) cell, which is frequently used for radiacmeters, a penlight (AA size) battery is considered more appropriate for this application, for the sake of smaller overall instrument size; and also, because it provides ample power considering the modest load current. A commercial rechargeable NiCd, type CH500 (Eveready) battery was used in the experiments so far (Table 1). The DC converter uses a high frequency switching oscillator design, similar to one described by Oak Ridge National Laboratory (ORNL, reference 6).

With the electrometer radiacmeter as a load on the ±12 V output of the converter (at +85, -122 microamperes respectively, i.e., 2.5 mW) the current drawn from the (1.3 V) battery is typically 4 mA, (5.2 mW). Thus, the converter efficiency is 2.5/5.2 or 48% (Note: At these rather low power levels higher efficiencies are difficult to realize, because certain losses remain relatively constant, regardless of output power delivered to load).

5. SOLAR POWER OPERATIONAL EXPERIMENTS

Only a few experiments were performed so far, with generally encouraging results. Obviously, availability of solar power is totally dependent on atmospheric and weather conditions, assuming the solar panel is positioned such that it has the benefit of sunshine, to the maximum degree, on sunny

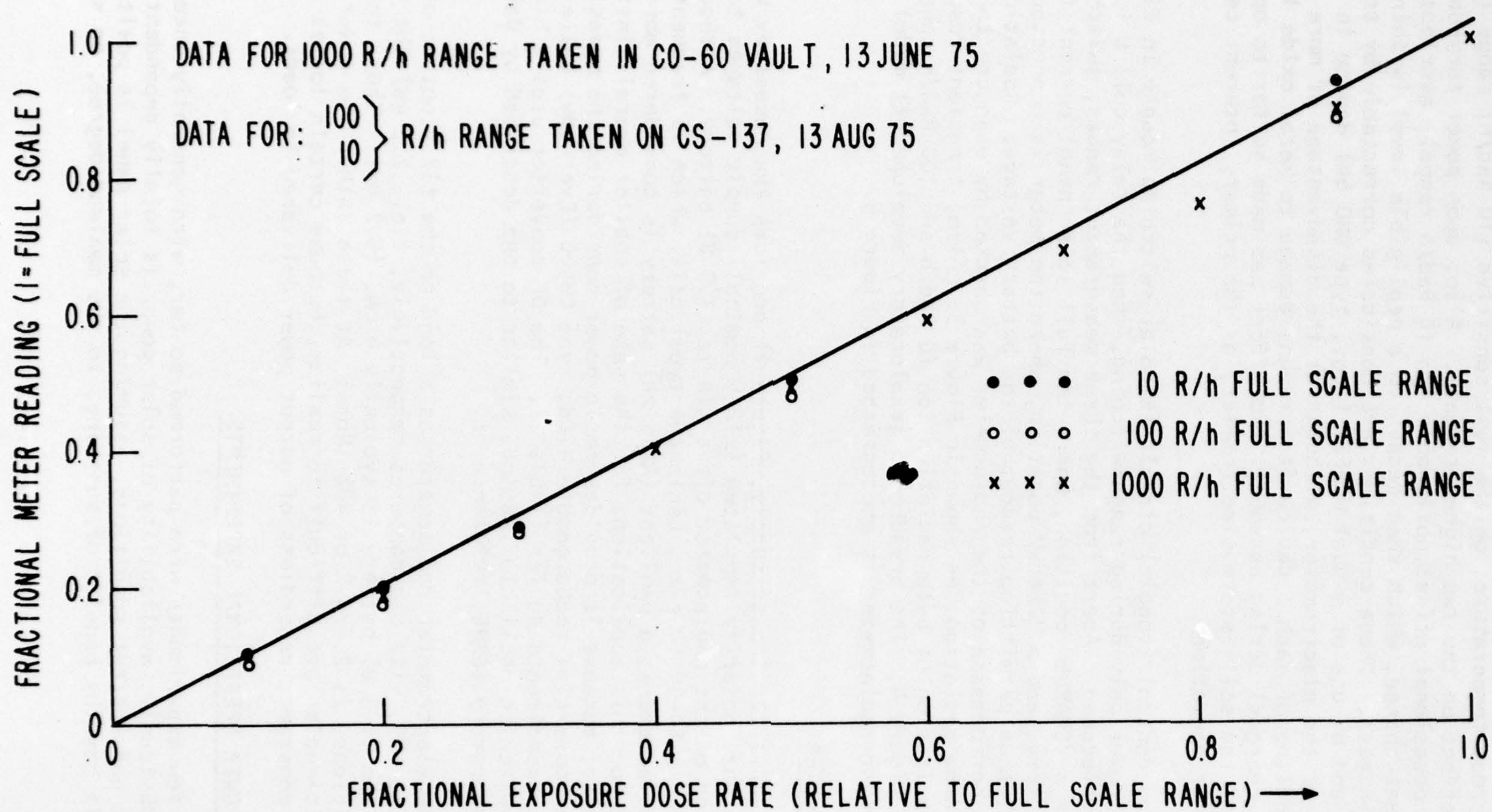
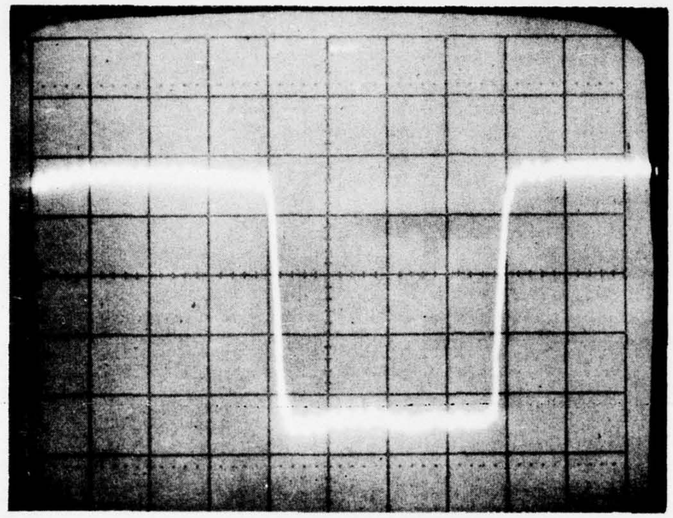


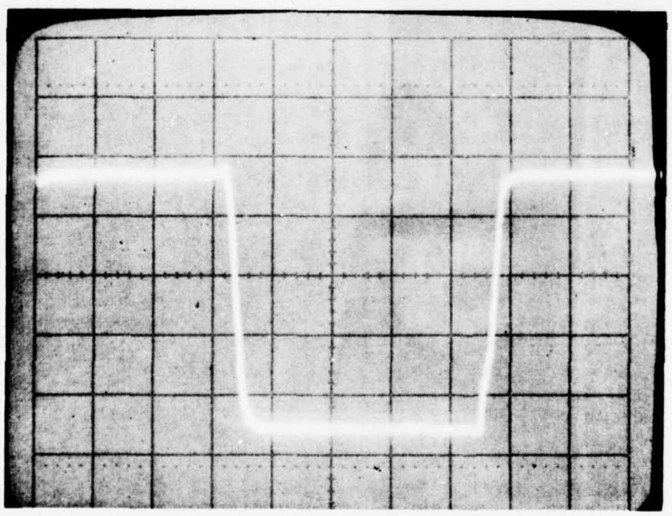
Figure 3. Radiation Calibration Test, Solar Power Radiacmeter



(A)

10 R/h - Range

Negative Deflection
Represents Approximately
Full-Scale Meter Reading
(10 R/h)



(B)

100 R/h - Range

Negative Deflection
Represents Approximately
Half-Scale Meter Reading
(50 R/h)

Vertical Scale: 1 V/cm

Figure 4. Response of Solar Radiacmeter
to Step Input of Radiation
(from TS-784/PD Beta Calibrator)
Horizontal Scale: 0.5 sec/cm

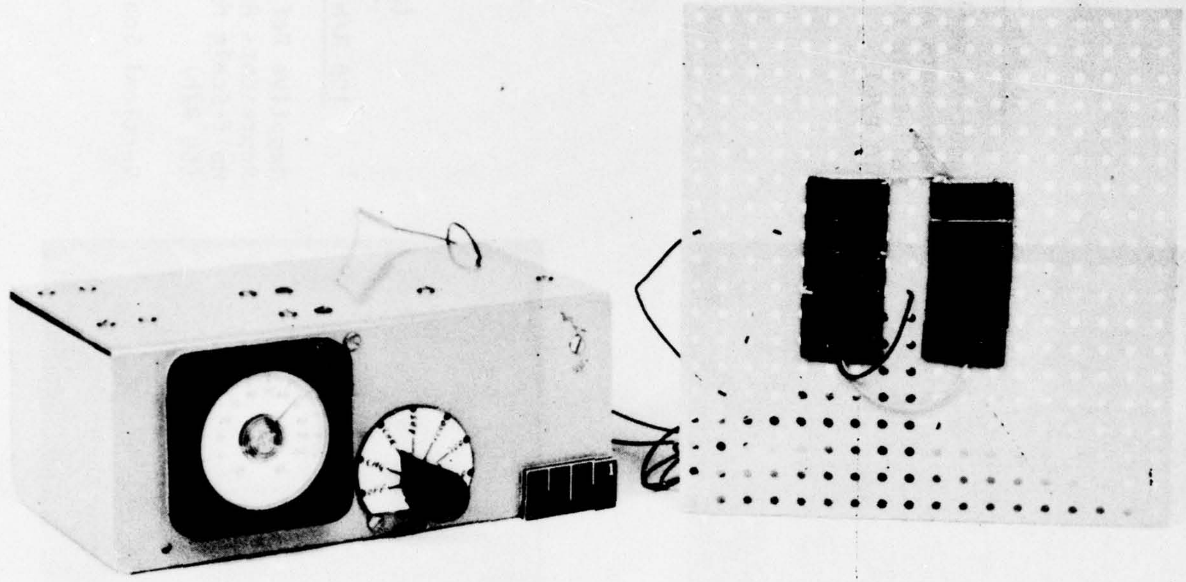


Figure 5. Solar Power Radiacmeter (Experimental Model), with Solar Panel (20 cm^2)

Table 1

Characteristics of CH-500 Type NiCd Battery (Eveready) 1)

Cell Type	Cylindrical Cell ("AA")
Voltage	1.25 V
Nominal Capacity	500 mA-hours (to 1.1 Volt, rated at 50 mA)
Approximate Weight	0.8 oz (22.7 g)
Volume	0.42 cubic inches (6.9 cc)
Nominal Cycle Life	1000 cycles
Discharge Temperatures	-4° F to +113° F
Storage Temperatures	-40° F to +140° F

1) "Eveready" Battery Applications and Engineering Data, 1971 Edition by Union Carbide Corporation.

days. In our experiments this was accomplished by attaching the (20 cm^2) solar panel to a lab window, facing approximately south (first experiment in Bldg. 51, 2nd floor; 2nd experiment in Bldg. 10A, Evans Area, Fort Monmouth, New Jersey). The panel was in a reclined position, looking into the sky, so as to be nearly perpendicular to the incident sun rays.

a. Solar Energy Experiment with Constant Operation of Radiacmeter

In this experiment the radiacmeter was constantly exposed to (Bremsstrahlung) radiation from a Sr-90 (TS-784) source, with the instrument left in an ON (operating) mode all the time, for the duration of this (two-week) experiment. Electrical parameters of interest were monitored, as indicated in the schematic of Figure 6, namely:

V_{in}	-	Voltage across solar panel
I_{in}	-	Current from solar panel
I_L	-	Load current (into DC converter/ radiacmeter)
I_B	-	Current into (or from) NiCd battery
V_B	-	NiCd battery voltage
e_o	-	Output voltage of radiac's electrometer

These parameters were monitored and recorded automatically by means of a data logger, once every hour, for 341 hours (about two weeks, from 25 April to 9 May 1975), totalling 2,046 printed numbers. One ohm resistors were used for convenient current to voltage conversion, causing minimal voltage errors. The solar panel itself was composed of two parallel strips of five cell elements each connected in series. This combination provides for a typical open-circuit voltage of 2.55 V (under irradiance), with peak short circuit currents of up to approximately 50 mA, depending on light exposure (Figure 7).

The solar panel and battery were isolated by a silicon diode (shunted by a Germanium diode, for low forward voltage drop at low currents).

The weather conditions during the observation period were rather variable and are reflected in the profile (histogram) of solar power input from solar panel (P_i), plotted as a function of time, in Figures 8A, 8B and 8C.

From the recorded data the total solar energy input (delivered by solar panel) was computed, as an approximation, by

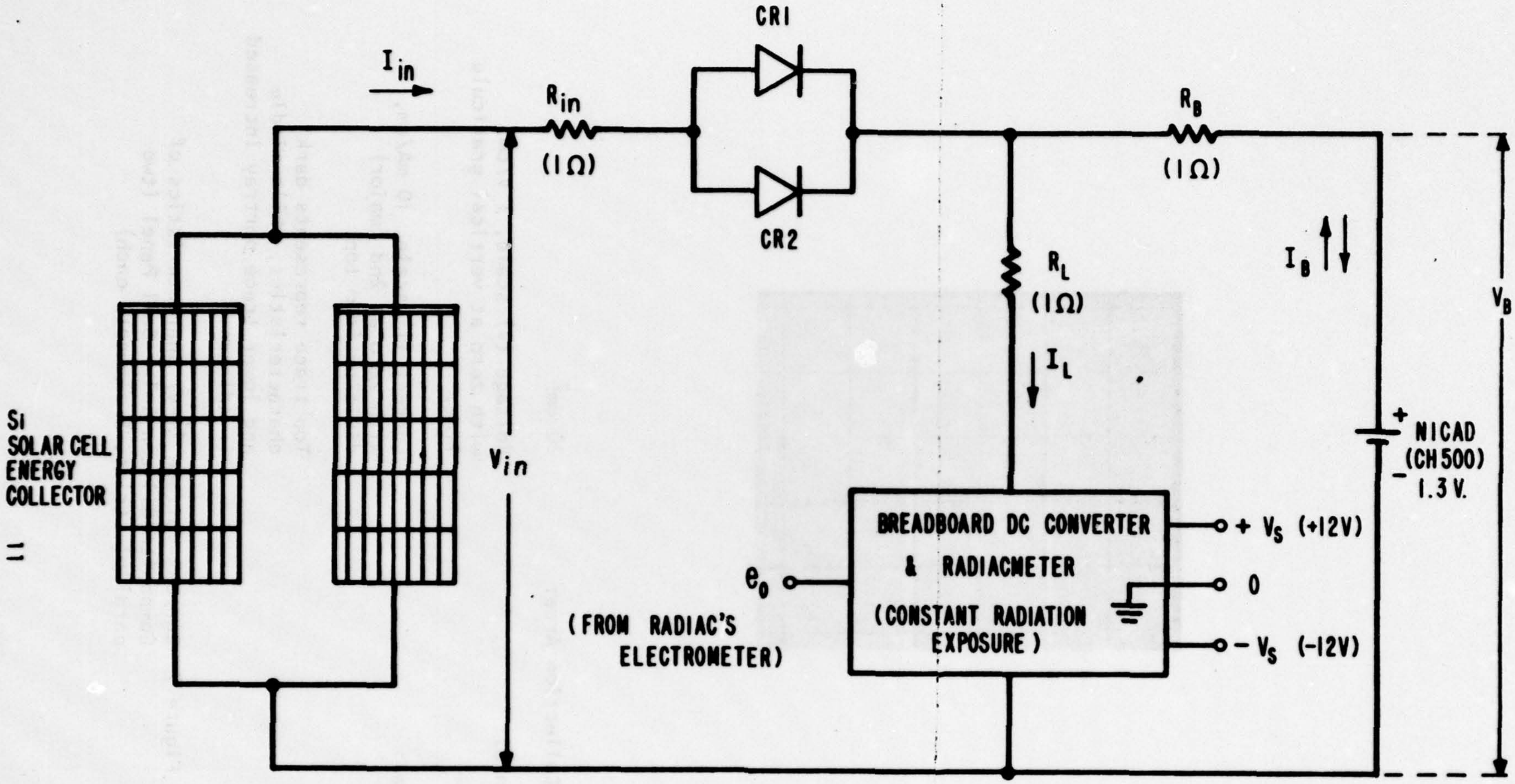
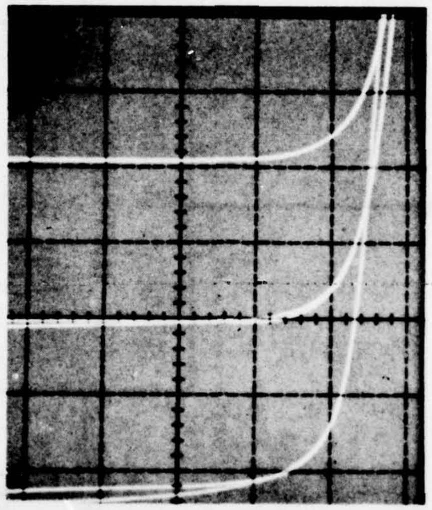


FIG. 6 SOLAR CELL AND (NICAD) BATTERY CHARGE AND TEST CIRCUIT FOR SOLAR POWERED RADIACMETER (BREADBOARD)



Total Collection Area:	20 cm^2
Horizontal:	Voltage (V) scale, 1 V/cm, with zero at vertical graticule line.
Vertical:	Current (I) scale, 10 mA/cm, with zero at 2nd (major) division from top.
Note:	Top trace represents dark characteristics, while middle and lower trace portray increased irradiance.

Figure 7 Current-Voltage (I-V) Characteristics of Composite Silicon Solar Cell Panel (two parallel strips, 5 elements each)

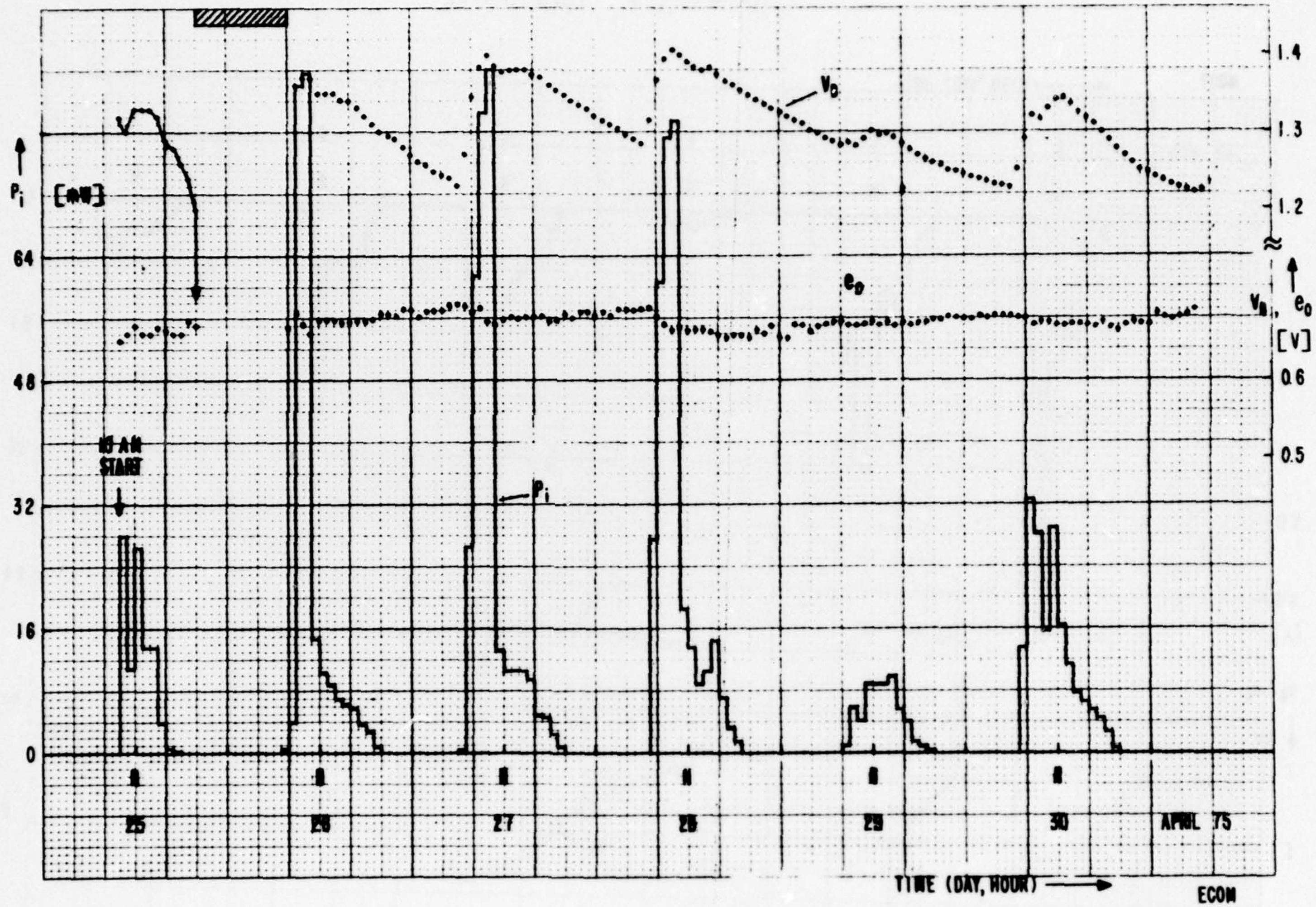


Figure 8(A). Solar Radiac
Test Data

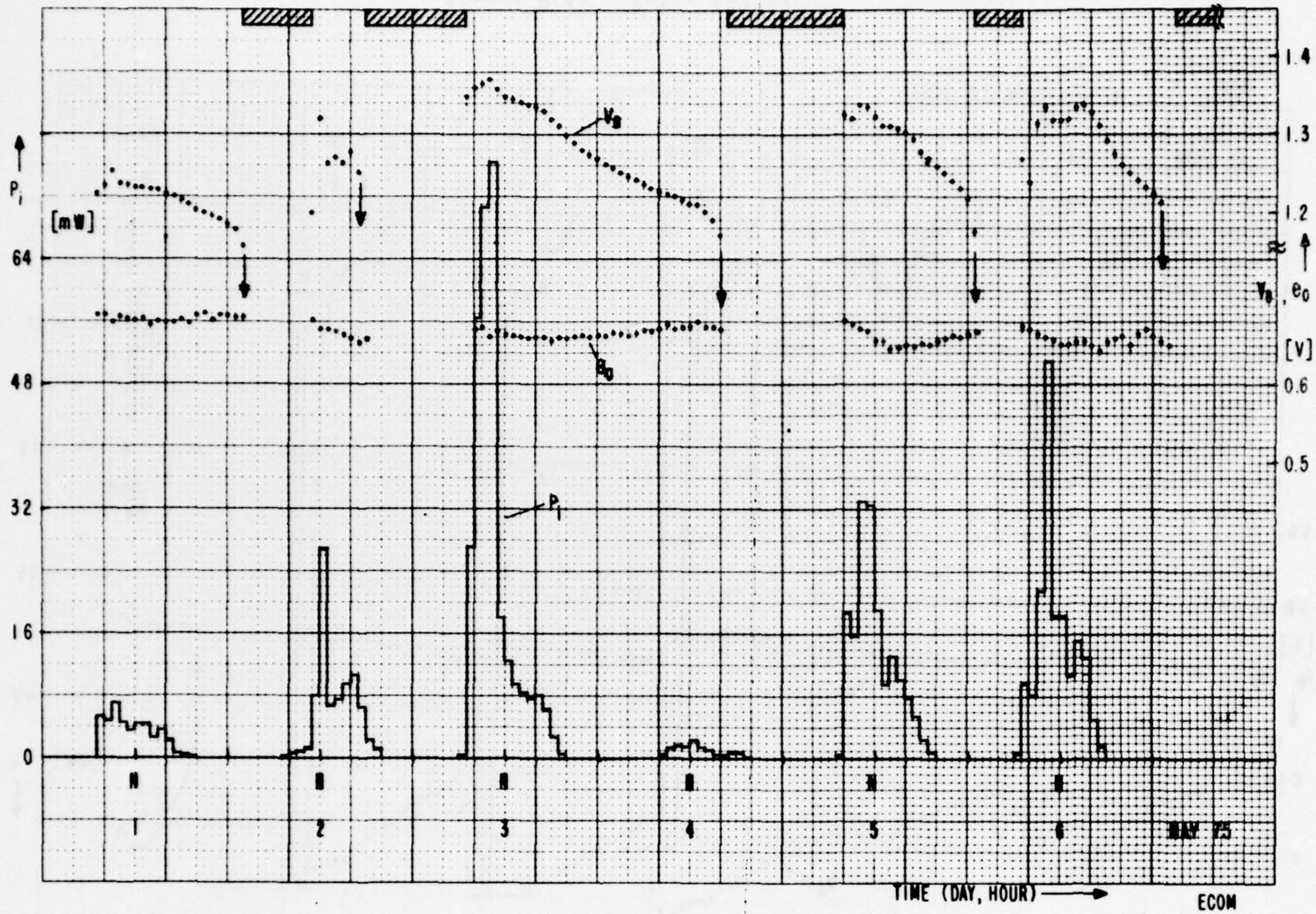


Figure 8(B). Solar Radiac Test Data (Cont)

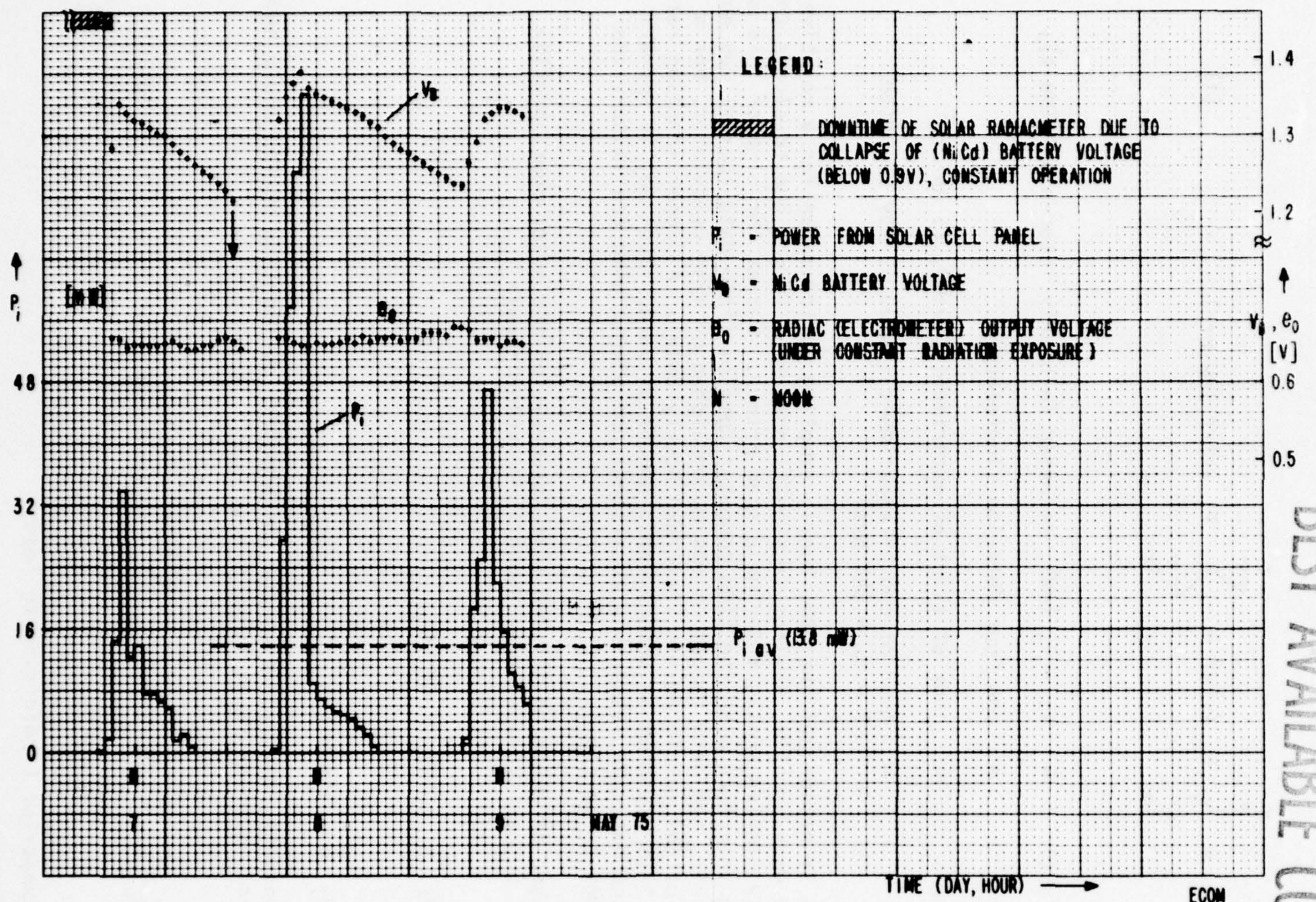


Figure 8(C). Solar Radiac Test Data (Cont)

$$W_i = \int_{t_o}^{T} P_i\ (t)dt \cong \sum_{t_o}^{T} P_i\ (t)\cdot t\ (\text{mW-hrs}) \qquad (1)$$

where

$P_i(t)$ = $V_i \cdot I_i$ (mW), recorded in hourly intervals (time t);

t = one hour duration (increment)

t_o = hour of start of experiment (10:00, 25 Apr 75)

T = hour of end of experiment (15:00, 9 May 75, with $T - t_o = 341$ hrs)

It is recognized that the hourly sampling period makes for a relatively coarse data profile, subject to significant error (e.g., due to clouds temporarily dimming sunlight during a scan print). But at the time of this work a data interface with the ECOM computer complex (from data logger) was not available, and data reduction was accomplished by hand calculator, for a total of 341 sample points (recorded hourly data). A higher sampling rate would have produced an unmanageable amount of data. Even so, it appears that the data are reasonably consistent and permit some preliminary conclusions to be drawn.

Based on equation (1) the time integral for the solar power profile yields a total solar energy input (from solar panel)

$$W_i = 2{,}560.27 \text{ mW-hrs}$$

or

$$W_i \cong 2.56 \text{ W-hrs}$$

Constant load operation (of radiacmeter) during this period would have required, similar to equation (1)

$$W_L = \int_{t_o}^{T} P_L(t)dt \cong \sum_{t_o}^{T} P_L(t)\cdot t\ (\text{mW-hrs}) \qquad (2)$$

with subscript L referring to load;

or approximately

$$W_L \cong 1.2\ (V) \times 4\ (mA) \times 341\ (hrs)$$

$$W_L \cong 1637 \text{ mW-hrs}$$

The actual recorded energy into DC converter (load) was determined to be 1516 mW-hrs (taking into account 66 hours downtime).

Considering that there was some initial charge on NiCd battery, one might infer that the radiacmeter should have operated continuously during the test period; which it did not (see Figures 8A, 8B, and 8C). Based on the recorded data (as reflected in Figures 8A, 8B, and 8C) the radiacmeter was incapacitated (due to insufficient battery voltage) for 66 hrs/341 hrs or 19% of the test period (mostly during night time hours).

However, closer examination of data suggests an appreciable loss of collected power via dissipation in the isolation diodes, namely

$$W_D = 855 \text{ mW-hrs (Diode Energy Loss)}$$

Thus, the available energy for both radiac operation (load) and battery chargeup was, at best,

$$W_{Li} + W_b = W_i - W_D \tag{3}$$

or

$$W_{Li} + W_B = 2{,}560 - 855 = 1{,}705 \text{ mW-hrs}$$

with W_{Li} signifying energy into load (converter/radiac) from solar panel.

For reduced losses the isolation diode should have low forward voltage drop (such as obtainable from a low-power Schottky diode).

From the circuit arrangement of Figure 6, the charge current I_B into the battery can be readily determined as

$$I_B = I_{in} - I_L \tag{4}$$

where I_{in} is the current delivered by solar panel and I_L is the load current (into DC converter/radiacmeter). In the absence of solar power i.e., for $I_{in} < I_L$, the charge current I_B in equation (4) changes sign and becomes a (negative) discharge current (I_B), from battery into load. In terms of equation (3) and equation (4) the recorded data must, therefore, be examined with regard to energy flow into, or out of, NiCd battery, in relation to energy flow into the load. Generally speaking, during day-time (sunlight) hours, the energy input W_i suffices for both load operation and battery charge, while at night ($W_i = 0$) instrument operation relies, of course, entirely on energy from NiCd battery. On overcast days, i.e., with reduced W_i, there may be just enough W_i to operate instrument (W_L), with no energy

left for battery charge. Examination of the recorded data (and Figure 6) with respect to energy W_{li} from solar panel directly into load (for $P_i > 0$) reveals this component to be

$$W_{li} = \int_{t_o}^{T} P_{Li}(t)\ dt \cong \sum_{t_o}^{T} P_{Li}\ (t) \cdot t \text{ (mW-hrs)} \qquad (5)$$

where

$$P_{Li}\ (t) = I_L \cdot V_B \text{ for } (I_{in} - I_l) \geqq 0 \text{ (at time t);}$$

or

$$W_{Li} = 659.88 \text{ mW-hrs}$$

Consequently, the net energy for battery charge-up can be determined from equation (3) as

$$W_B = W_i - W_D - W_{li}$$

or

$$W_B \cong 2,560 - 885 - 660 = 1045 \text{ mW-hrs}$$

The energy situation, i.e., that net energy available for battery charge may, alternatively, be analyzed in terms of charge. From the data and referring to equation (4), we can compare total charge into battery Q_B^+ versus total charge removed from battery Q_B^-, namely

$$Q_B^+ = \int_{t_o}^{T} I_B^+ (t)\ dt \cong \sum_{t_o}^{T} I_B^+ (t) \cdot t = \sum_{t_o}^{T} q_B^+ \text{ (mA-hrs)} \qquad (6)$$

q_B^+ = Incremental hourly charge into battery

Q_B^+ = 762.1 mA-hrs (Charge into battery)

Q_B^- = 687.3 mA-hrs (Charge from battery)

Thus, about 11% less charge was retrieved from (NiCd) battery than was supplied (from solar panel), during experiment. Although this difference is somewhat questionable due to the coarseness of data sampling (summation of discrete hourly data in lieu of continual integration or higher rate sampling), it is consistent with an expected loss of charge in battery on account of self-discharge. Self-discharge curves for nickel-cadmium cells found in the literature (reference 7) suggest a decline of rated capacity of 10 to 20% in the first one or two weeks after charge, with a more gradual (slower) decline thereafter. Some further uncertainty in this comparison arises from the fact that the status of initial and final charge on battery during experiment was

not considered as it is difficult to ascertain. Pursuing the charge concept further, it is instructive to derive from it the energy into battery, by way of equation (6) and

$$W_B^+ = \int_{t_o}^{T} I_B^+(t) \cdot V_B \, dt \cong \sum_{t_o}^{T} q_B^+ \cdot V_B \text{ (mW-hrs)} \qquad (7)$$

From the data this is found to be

$$W_B^+ \cong 1031.8 \text{ mW-hrs}$$

which is in good agreement (within 2%) with the result obtained earlier, based on energy balance in accordance with equation (3), solved for W_B. Thus, the measurement and data sampling technique of Figure 3 permits an accounting of solar energy intake and dissipation in the system. With more frequent sampling and immediate computer-compatible data storage and computer data processing a rather complete and accurate accounting of energy flow would be possible.

Another point of interest from this experiment is the stability of the output signal, e_o, from the electrometer/radiacmeter, under constant radiation exposure. From the data over the two-week observation period, this parameter (e_o) was found to remain within +4.5 and -3.7% of an average value of 669 millivolts (corresponding to an indicated dose-rate of approximately 7.5 ±0.3 Rad/hr).

b. Solar Energy Experiment with Intermittent Operation of Radiacmeter

In contrast to the preceding experiment (paragraph 5 a), the load (DC converter/radiacmeter) was operated for only a few hours each day, while the NiCd battery was permitted to receive charge from solar panel continuously (the amount depending on weather conditions). The solar panel was "looking" through a window facing southeast in Building 10, Evans Area.

Radiacmeter ON/OFF cycling was automated via a cam-controlled microswitch timer, with approximately (at least) five hours daily ON-time (1 to 6 p.m.). As in the earlier experiment, the radiacmeter remained constantly exposed to a fixed level of radiation (6.1 Rad/hr), with upscale meter readings occurring, of course, only during the ON-intervals of the radiacmeter. Electrical parameters were monitored and recorded as in first experiment.

This (intermittent operation of radiacmeter) experiment extended over a period of 31 days (19 February - 21 March 1976). However, during the first five days the cam-controlled timer was being readjusted as the ON-time was found initially to be less than five hours. Also, during one weekend, the data logger's recorder ran out of chart paper, causing loss of data for one day. Thus, the following results are based on a lesser, but controlled time period of 25 days. Only a quick-scan review of this data was made to date, as more detailed analysis would require transfer of data into computer compatible medium (e.g., teletype tape) for computer data processing.

Significant results or conditions are tabulated as follows (Table 2):

Table 2

Results of Experiment (Intermittent Operation of Solar Radiacmeter)

Duration of (Intermittent Operation) Experiment		25 days
Weather Conditions: (approximately)	Cloudy, rain (snow) or overcast:	9 days
Beta Radiation Exposure (TS-784):	Constant Exposure	6.1 Rad/hr
Downtime of Solar Radiacmeter (when power ON):		None (measured radiation for five hours every day, for a total ON-time of 125 hours).
Stability of Radiacmeter (Electrometer) Output Signal:		Standard Deviation (σ) from average signal (0.5521 Volt) was 0.6% (5.5 millivolt), with worst case excursions of +4.7 and -3.5%.

6. CONCLUSIONS

The work reported, although by itself preliminary in scope and as yet incomplete, in the author's view, demonstrates feasibility and the "free energy" merit of a sun-powered radiacmeter. Conceptually, such an instrument can be further compressed in size, compared to the instrument breadboarded in this work, by way of MSI or LSI and smaller components (switch, meter, potentiometers etc.). Also, conversion to digital (liquid crystal) display is conceivable at perhaps higher power demand. The question would then arise, where to mount the silicon solar energy collector. One approach would be to mount them on one or several suitable spots on instrument case, or carrying pouch (strap) affording exposure to sunlight in normal mode of carrying and operating instrument in the field. Alternatively, if the instrument itself is too small to offer sufficient usable surface area for solar cells, it could be mounted on a supporting strap (for example on arm), with solar cells (rigid or flexible type) embedded on it ("armband" style). Other questions to be addressed concern such areas as physical rigidity of solar panel (and protective, transluscent cover), nuclear vulnerability, shelf life (in storage) of solar panel and (NiCd) battery (assuming battery not installed in instrument during extended period of storage), inclusion of a battery charger (from 115 V AC and 24 V vehicular DC) into instrument, etc.

It would seem appropriate to recommend further consideration of the idea of a solar-power radiacmeter and development of a prototype, for possible evaluation by the Army, under technical and operational feasibility testing (TFT/OFT) or innovative testing (AR 70-10). Such further testing and demonstration would be required to stimulate a formal requirement with user.

Apart from a dose-rate meter, extension of solar power to other low power radiac applications also appears feasible. Any such development will require close coordination with ECOM's Power Sources Division regarding selection and possible parallel development of a miniature rechargeable battery.

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